REVITALIZING TRADITIONAL METAL CRAFTS: A KNOWLEDGE TRANSFER EMPOWERING SUSTAINABILITY THROUGH BIOMIMICRY DESIGN

MEREVITALISASI KERAJINAN LOGAM TRADISIONAL: TRANSFER PENGETAHUAN YANG MEMBERDAYAKAN KEBERLANJUTAN MELALUI DESAIN BIOMIMIKRI

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Abstract

This paper aims to empower biomimicry design through knowledge transfer for the sustainability of traditional Malay metal crafts, particularly in Malaysia. Recent studies have highlighted a regression in the acceptance and practice of cherished local skills, focusing on the dying art of metalware and jewellery. The primary objective of this project is to ensure the continued practice of metalsmithing by seamlessly integrating traditional craftsmanship with contemporary technological trends by implementing a comprehensive knowledge transfer targeting Malaysia's youth. The concept of "moditional" encapsulates the transition of these traditional practices into modern production methodologies. The core idea behind "moditional" is to expose and educate the local communities in Malaysia on appreciating traditional and modern local craft design. This initiative aligns with the Sustainable Development Goals, explicitly targeting quality education, economic growth, and creating decent work opportunities for all communities. The overarching goal of the knowledge transfer is to facilitate the transfer of skills, experiences, and best practices in computer-aided design (CAD), computer-aided machines (CAM), and craftsmanship. This program encompasses the responsible handling of precious materials, 3D data visualization, prototyping, machining, and hands-on craftsmanship. Through tacit knowledge, it is anticipated that the art of national heritage crafts will thrive and preserve traditional culture in metalware and jewellery.

Keywords: *Biomimicry, Malay Traditional Craft, Metalsmithing, Technology, Knowledge Transfer*

Abstrak

Makalah ini bertujuan untuk memberdayakan desain biomimikri melalui transfer pengetahuan untuk keberlanjutan kerajinan logam tradisional Melayu, khususnya di Malaysia. Studi terbaru telah menyoroti kemunduran dalam penerimaan dan praktik keterampilan lokal yang dihargai, dengan fokus pada seni perkakas logam dan perhiasan yang mulai punah. Tujuan utama proyek ini adalah untuk memastikan keberlangsungan praktik pengerjaan logam dengan mengintegrasikan keahlian tradisional dengan tren teknologi kontemporer secara mulus melalui transfer pengetahuan komprehensif yang menyasar generasi muda Malaysia. Konsep "modional" merangkum transisi praktik tradisional ini ke dalam metodologi produksi modern. Inti gagasan di balik "modional"

adalah untuk mengekspos dan mengedukasi masyarakat lokal di Malaysia tentang apresiasi desain kerajinan lokal tradisional dan modern. Inisiatif ini sejalan dengan Tujuan Pembangunan Berkelanjutan, yang secara eksplisit menargetkan pendidikan berkualitas, pertumbuhan ekonomi, dan penciptaan lapangan kerja layak bagi seluruh masyarakat. Tujuan utama transfer pengetahuan ini adalah untuk memfasilitasi transfer keterampilan, pengalaman, dan praktik terbaik dalam desain berbantuan komputer (CAD), mesin berbantuan komputer (CAM), dan keterampilan kerajinan. Program ini mencakup penanganan material berharga secara bertanggung jawab, visualisasi data 3D, pembuatan prototipe, pemesinan, dan keterampilan kerajinan tangan. Melalui pengetahuan tacit, diharapkan seni kerajinan warisan nasional akan berkembang dan melestarikan budaya tradisional dalam bidang logam dan perhiasan.

Kata Kunci: Biomimikri, Kerajinan Tradisional Melayu, Kerajinan Logam, Teknologi, Transfer Pengetahuan

INTRODUCTION

Traditional Malay metalwork—covering gold, silver, and brass ware painstakingly produced along Malaysia's east-coast corridors for more than two centuries—constitutes a living archive of communal belief, hierarchy, and ecological observation (Syed Ahmad et al., 2023). While the craft once flourished as the so-called "Cradle of Malay Culture," longitudinal surveys now reveal precipitous declines in output, artisan numbers, and domestic demand, driven by an ageing master-smith cohort, surging bullion costs, and design vocabularies that resonate poorly with Generation Z consumers (Syed Ahmad et al., 2023). This contraction is especially troubling because each repoussé surface and filigree flourish encodes syncretic influences—from Srivijaya Hindu-Buddhist symbolism to British-Malaya aesthetics—rendering the artefacts both utilitarian objects and primary documents of Malay intellectual history (Syed Ahmad et al., 2023). Preserving such multilayered iconography aligns squarely with UNESCO's call to safeguard intangible cultural heritage in danger of disappearance, yet policy instruments remain fragmented and under-resourced.

Current scholarship proposes a dual revitalisation pathway. First, alignment with Sustainable Development Goals (SDG 8: decent work; SDG 12: responsible production) can stabilise supply chains and secure fair wages, thereby counteracting the economic precarity that fuels workforce attrition (Syed Ahmad et al., 2023). Second, biomimicry-driven design frameworks—adapting offer an ecologically attuned aesthetic capable of re-energising market appeal without erasing heritage symbolism (Danish et al., 2024). Complementing these material strategies, immersive technological toolkits have emerged as potent platforms for codifying tacit hammer-and-chisel skills and transmitting them to novice makers through haptic feedback and micro-credential modules (Garcia & Verlinden, 2024). Early trials in craft-specific classrooms report heightened learner engagement and reduced error rates, hinting at scalable solutions for intergenerational knowledge transfer and heritage preservation. Against this backdrop, the present study interrogates how biomimicry-infused design innovation, anchored in SDG principles and supported by technological trend pedagogy, can arrest the decline of Malay metalwork. Specifically, it (i) maps historical and socio-economic pressures affecting the craft, (ii)

evaluates biomimicry prototypes co-created with master smiths and young designers, and (iii) tests an apprenticeship model for skill transmission.

By integrating cultural, ecological, and technological lenses, the research aims to position Malay metal craft not merely as a relic of the past but as a regenerative industry compatible with contemporary sustainability agendas. Below in Figure 1, cultural artefacts are tangible representations of a society's values, beliefs, and traditions. The diagram organises these artefacts into eight functional and symbolic classifications: Symbol, Gift, Ornaments/Jewellery/Accessories, Wedding Ceremony, Accessories, Weapon, Ceremonial/Regalia, and Utensils/Kitchenware. Each category highlights the diversity and richness of cultural expression. For example, Symbols like trophies and plaques serve commemorative or representational purposes, while Gifts such as coins reflect customs of generosity or ceremonial exchange. Ornaments and jewellery, including belt buckles and brooches, are associated with adornment and personal identity. Items used in wedding ceremonies, like trays and egg flowers, represent ritual practices and social traditions. Accessories—such as trinket boxes and cosmetic containers—offer insights into daily life and aesthetic values. Meanwhile, Weapons like the keris embody cultural identity, martial heritage, and craftsmanship. Ceremonial regalia like drums and sceptres are essential to rituals and governance. Lastly, Utensils and kitchenware—teapots, pepper crushers, and more—reflect utilitarian yet artistically crafted tools of domestic life. Together, these categories present a comprehensive view of how material culture preserves and conveys intangible heritage through physical forms.

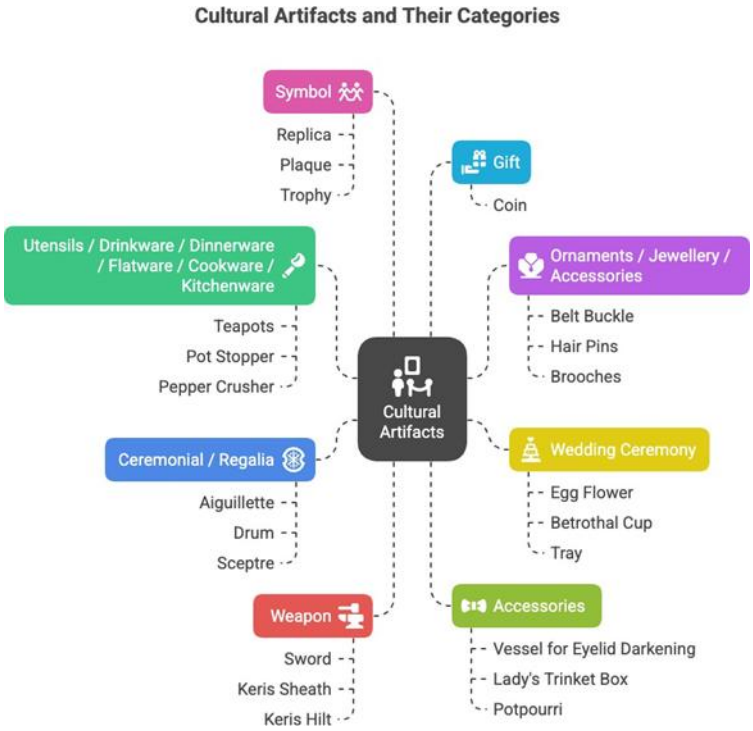

Figure 1. This visual diagram categorises cultural artefacts into eight main groups, illustrating how traditional objects are classified based on their use, symbolism, and function incultural practices—from utensils and ceremonial regalia to symbolic and decorative items

The traditional Malay metal craft reflects an ingenious integration of environmental elements, where natural forms serve as the primary source of aesthetic and symbolic inspiration. Artisans meticulously select organic motifs—such as leaves, flora, and fauna—to form the foundation of their design language, thereby embedding environmental reverence within the craft's visual identity. This deep-rooted relationship with nature aligns with a broader philosophical worldview in Malay society, in which form, pattern, and function are not merely decorative, but represent layers of cultural, spiritual, and metaphysical meanings (Abdullah & Zainal, 2021). Within the context of Islamic and Malay aesthetics, nature is often interpreted as a divine creation, shaped through biological processes by the will of Allah. This aligns with the Malay worldview, where natural elements are regarded not only as artistic inspiration but also as a conduit to spiritual and philosophical reflections (Mohd Yusoff et al., 2022). The design language in traditional Malay metalwork exemplifies this philosophy through its intricate symbolic forms.

Contemporary interpretations of Malay traditional design are increasingly aligning with biomimicry—a concept popularised by Janine Benyus in 1997, which refers to the practice of learning from and emulating nature's time-tested patterns and strategies to solve human design challenges. Biomimicry has since evolved into a robust interdisciplinary framework that promotes sustainable and resilient design innovations (Kennedy et al., 2020). As a form of "innovation inspired by nature," biomimicry offers tools for solving design problems through systemic thinking, form development, structural optimization, and material efficiency, all modelled after biological intelligence (Noriega et al., 2023). The application of biomimicry in craft and design fosters an empathetic and ecological design process that emphasizes coexistence with the natural world. Rather than merely replicating natural forms, biomimicry encourages a deeper understanding of natural principles, allowing artisans and designers to interpret nature's functionality and adaptability into meaningful and sustainable outputs (Yunus & Mokhtar, 2024). For Malay metal artisans, adopting biomimetic approaches may serve as a pathway to revitalize traditional practices, enhance innovation, and reinforce ecological awareness, while maintaining the philosophical underpinnings of Malay culture (Rahman et al., 2025).

LITERATURE REVIEW

The revitalization of traditional metal crafts is a renewal process that emphasizes preserving cultural values while strengthening competitiveness through innovation. This process involves a conscious effort to revive fading traditional practices and skills by adapting them to the needs of the times. In this context, knowledge transfer is key, as it enables the intergenerational transmission of skills, the exchange of ideas between craftsmen and designers, and the integration of traditional knowledge with modern technology. Through ongoing collaboration, craft communities can strengthen their creative capacity and broaden their understanding of the functional and aesthetic value of their products, thus creating continuity between tradition and innovation.

Biomimicry design presents an approach capable of inspiring the creative process in the revitalization of metal crafts. By imitating the forms, structures, and systems found in nature,

biomimicry encourages the creation of designs that are efficient, sustainable, and aligned with ecological principles. The application of this approach not only produces products of high aesthetic value but also strengthens environmental awareness in craft practices. When knowledge transfer and innovation in biomimicry design are balanced, artisans become more empowered, independent, and creative in facing the challenges of modern industry. Thus, the revitalization of traditional metal crafts through biomimicry-based knowledge transfer has the potential to create social, economic, and ecological sustainability rooted in local wisdom yet relevant to global demands.

METHODS

This research began based on literature studies, and exploratory research was carried out to achieve the proposed objective. Through the focus group discussions (FGD) with the experts referred to in the paper (Syed Ahmad, 2023), the data collected was able to sustain the Malay traditional metal crafts through the ten keys of sustainability of craft, as in Figure 2.

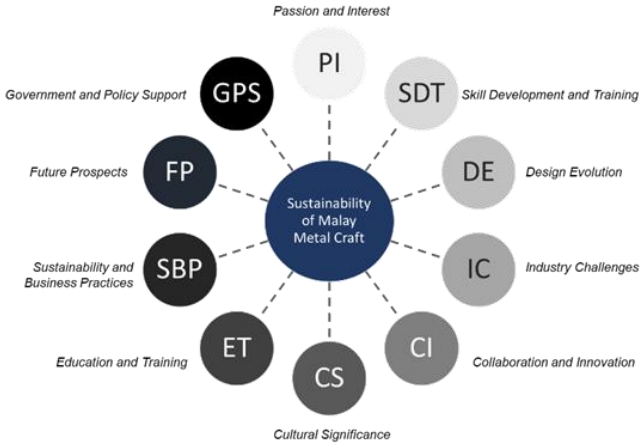

Figure 2. Ten keys to the sustainability of Malay metal craf

This study focuses on four phases: research plan, empathise, finding with implementation, and summary to conclude. Subsequently, the data were analysed using thematic analysis to identify and report the repeating coding themes gained from the discussion session. Furthermore, design exploration was conducted to elaborate on the traditional approach in transitioning previous traditions into the contemporary design for knowledge transfer. Figure 3 shows the whole research process involved.

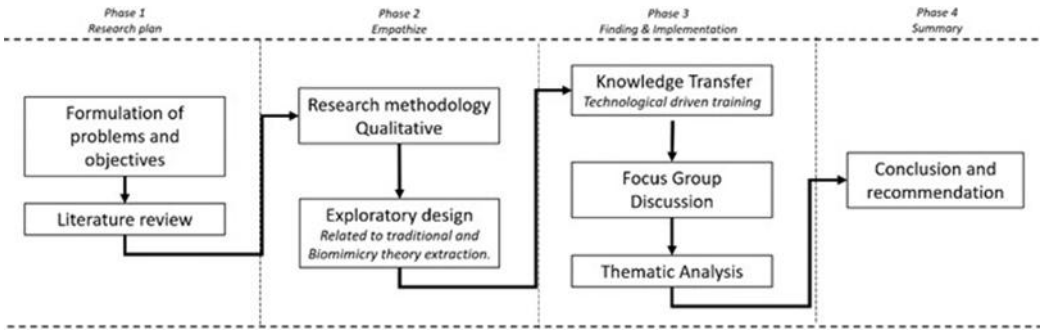

Figure 3. Research flowchart

Exploratory Design

Exploratory design in Malay metal craft encapsulates a process of innovation and experimentation within the context of this traditional art form. It involves the deliberate departure from established tradition into an exploration that infuses contemporary elements through moditional concept. In this research, the subject matter betel nut set, and container have been selected based on previous FGD recommendations. By adopting the Biomimicry Design Spiral by Carl Hastrich, the design was developed based on nature-inspired with six steps of sustainability development consisting of define, gather, abstract, ideate, emulate, and evaluate, as in Figure 4.

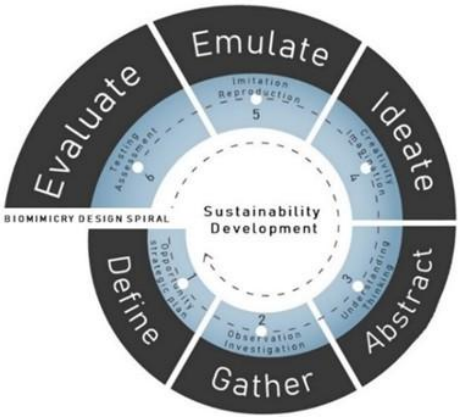

Figure 4. Biomimicry design spiral on sustainability development

Focus Group Discussion (FGD)

The focus group discussion involved youth from local communities who participated in evaluating the data obtained from the knowledge transfer program (KTP) and the design module produced through Biomimicry theory. These methods are analysed using coding, categorisation, and thematic analysis techniques to identify patterns, themes, and critical findings. Through this method, the research aims to highlight the importance of sustaining the cultural heritage of the Malay metal craft, explore its potential in nurturing community resilience and empowerment, and propose strategies for its revitalisation and safeguarding.

RESULTS AND DISCUSSION

Exploratory Design Based on Moditional Concept

Based on previous Malay traditional design collections in the 1920s – 1940s of betel nut containers, through design observation and understanding, we found out that local artisan ideates their design based on nature consisting of the form, shape and motif of betel fruit, betel leaf, vegetal, and floral elements. Figure 5 shows the compilation and design identification of Biomimicry elements to represent local Malay culture and environment.

Figure 5. Design observation and identification of the previous Malay traditional betel nut container

To create a design rooted in the moditional concept, an observational and analytical drawing was executed on the subject of the betel leaf. The essential elements and principles of art and design were employed to examine the betel

leaf's line, shape, form, pattern, and proportion. This study served as the foundation for conceptualising a moditional container, as illustrated in Figure 6.

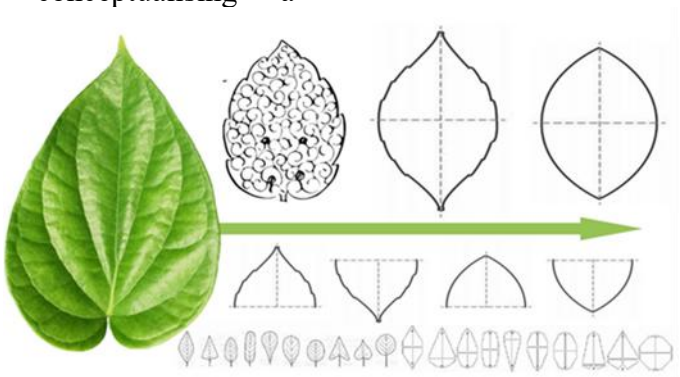

Figure 6. Observational and analytical drawing on a betel leaf

Through the implementation of ideation, the design process was developed to emulate and imitate the integration of traditional and technological design and craftsmanship.

Figure 7 indicates the design transition from the previous collection developed and generated through CAD software and the outcome combination between a rapid prototyping model using PLA material, combined with hand practice metal work, as a set of containers consisting of a body and cover. This outcome was created as a module for the Knowledge Transfer Program, participated in by twelve selected youths and two teachers from Kolej Tingkatan Enam Shah Alam (KTESA).

Figure 7. The design development of the container with modular concept

Technologically Driven Knowledge Transfer Approach

The knowledge transfer program aims to transfer skills, experience, and best practices in metalsmithing embedded with current design technology such as 3D modelling, CNC production, and rapid prototyping. The program typically involves creating training materials and providing hands-on learning and practice opportunities. Three main integration modules of knowledge transfer that consist of CAD to CAM and craftsmanship, as in Figure 8, were established for the learning activities derived from the design development process.

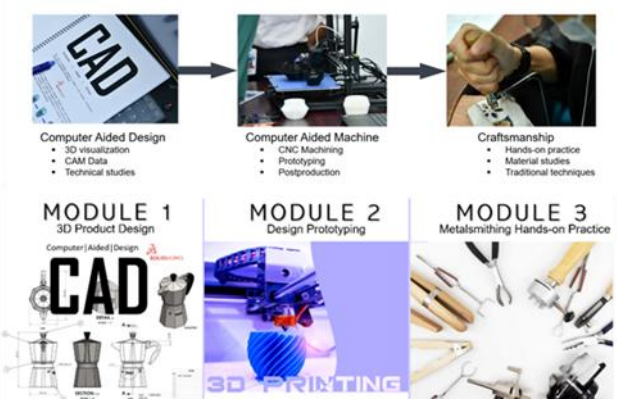

Figure 8. Three modules of the technology-driven knowledge transfer program in metalsmithing design

Focus Group Discussion

Focus group discussions have been conducted with twelve participants from the local youth; these discussions aim to evaluate the effectiveness of the KTP module. The discussion was held for an hour based on four main topics, which are i) The overall experience in KTP, ii) The design impression, iii) Handling material, machining, and craftsmanship, and iv) the Evaluation of practice-based learning. Based on the discussion related to all implementations of training, modules, design and understanding of knowledge, below is the thematic analysis of the coding theme and details in this research refer to Table 1.

Table 1.
The thematic analysis of knowledge transfer and focus group discussions

No	Theme	Description
1	Evolution of Understanding	The significant evolution in the understanding of skills in the field from the Knowledge Transfer Program
2	Perception of the Field	Participants' perceptions were initially seen as more engineering-oriented but evolving into a challenging and enjoyable discipline in metalsmithing design
3	Design Impressions	Positive impressions of the designs produced, including uniqueness, complexity, realism, nature-inspired and cultural motifs
4	Perceived Difficulty in Craftsmanship	Perceived difficulty in the craftsmanship process, which becomes more manageable with the training provided
5	Multidisciplinary Aspects	Recognition of the multidisciplinary nature of the course, connecting to physics, chemistry, entrepreneurship, and engineering.
6	Income Generation and Entrepreneurship	Belief in the potential of the skills acquired for income generation and entrepreneurship.
7	Potential Product Outcome	Based on the training, the participants believe the potential products, such as jewellery, accessories, and sculptures relevant to the outcome.
8	Combination of Hand Skills and Technology	Emphasis on the importance of combining traditional hand skills with technological advancements in the fabrication process.

9	Continuation of Handcrafting Techniques	Strong belief in the continuation of handcrafting techniques alongside modern technology.
10	Duration of the Course	Participants' suggestion is at least a one-week duration for the skills course especially concentration more for CAD and metalsmithing practice.

Figure 9 is based on thematic analysis coding to represent the effectiveness of sustainability of Malay metal craft through three main factors: design, knowledge transfer, and prospects. Each of these factors was significantly important to ensure the nation's sustainability of metal craft practice and industry. Furthermore, the elaboration of analysis in sustaining the Malay metal craft highlighted the preservation, evolution, innovation, economic development, and networking of traditional metalsmithing skills.

Metal craft traditions often have deep cultural and historical significance that embody previous generations' wisdom, techniques, and aesthetics. Knowledge transfer is vital in preserving traditional skills, ensuring they are passed down to future artisans. By transmitting knowledge from experienced artisans to younger generations, craft traditions can be sustained and kept alive. Hence, the continuity and evolution of craft practices evolve, reflecting changes in society, technology, and artistic trends. Knowledge transfer allows for the continuity and evolution of craft practices. Future stakeholders can build upon existing knowledge, refine techniques, and adapt to new materials and tools through the program. This ensures that craft traditions remain relevant and adaptable in a changing world.

Knowledge transfer in metalsmithing encourages innovation and creativity within the craft industry and community. Sharing knowledge and experiences will gain insights into different approaches, problem-solving techniques, and artistic perspectives. This exposure to diverse knowledge can inspire new ideas, experimentation, and the development of unique craft forms. This effort encourages the artisans and future stakeholders to push boundaries, combine traditional techniques with contemporary elements, and create innovative works of art.

Regarding economic and cultural development factors, metal craft contributes significantly to local economies by producing handmade goods, promoting tourism, and promoting cultural exchange. Transferring knowledge to the next generation ensures the continued production of high-quality craft products, supports local economies and preserves cultural heritage. Additionally, as craft traditions are passed down, they contribute to the identity and sense of pride within communities, strengthening cultural diversity and cohesion. Moreover, knowledge transfer in metal craft creates a strong sense of community and intergenerational bonding. It promotes mentorship relationships and creates opportunities for personal growth and development. It also allows transmitting intangible aspects, such as stories, values, and cultural significance associated with craft traditions. This exchange of knowledge builds the value of social connections, strengthens cultural connections, and enhances the overall well-being of the craft community.

The MBDS method focuses on design activities, beginning with extracting research ideas and

information to identify the best solution for translating design outcomes. Studying from benchmarks and designer references is beneficial in making decisions in the design process. Thus, observational and analytical drawing studies extract creative ideas for design optimisation. The crucial process in designing is an abstract that requires more development of ideas, refining, and analysing the design outcome. The assistants in Computer Aided Design were significantly effective in the design process. To emulate, visual design outcomes were generated into tangible and 3-dimensional prototype outcomes by producing technical specifications consisting of materials selection, precision on dimension, ergonomics, and fabrication aspects in joining and techniques in the making process. Lastly, the product outcomes were verified by the experts and end-users through an evaluation process on design satisfaction and acceptance.

CONCLUSION

In conclusion, preserving and revitalising the cultural significance of Malay metal craft stands as its primary goal. Multidisciplinary method to implement design practices, emphasising socio-economic impact on local communities aligned with SDGs through Quadruple Helix Model. This study proposes the Sustainability-Centric Integrated Practices (SCIP) Framework, as shown in Figure 10 a transformative approach that reimagines Malay traditional metalwork through a sustainability, education, and innovation lens.

Figure 10. Sustainability-Centric Integrated Practices (SCIP) Framework

SCIP integrates ecological, technological, and cultural dimensions by positioning Malay biomimicry design as the philosophical and aesthetic foundation for heritage revitalisation. This foundation is enhanced by technology integration, such as CAD/CAM, CNC machining, and rapid prototyping, bridging ancestral craft practices with modern tools. This strategic combination ensures cultural continuity while adapting to evolving market and societal needs. The framework is underpinned by the Quadruple Helix Model, bringing together academia, industry, government, and community to establish a collaborative ecosystem that advances inclusive development. Within this system, SCIP directly supports SDG 4 (Quality Education) by promoting intergenerational knowledge transfer through structured educational pathways. These pathways blend digital design technologies with traditional hands-on learning, enabling youth engagement, skill-building, and cultural literacy.

In terms of economic development, SCIP contributes to SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure), and SDG 12

(Responsible Consumption and Production). Through design-led entrepreneurship and responsible production practices, it supports artisans in commercialising culturally significant products without compromising authenticity. This not only strengthens local economies but also promotes environmental and cultural sustainability. Findings from the Knowledge Transfer Program and focus group discussions show that participants, especially youth, gained not only technical and creative competencies but also a deeper appreciation of the cultural narratives embedded in traditional metalwork. This confirms the potential of SCIP to foster innovation grounded in identity and ecological awareness.

The SCIP Framework redefines Malay metal craft not as a static tradition, but as a regenerative cultural ecosystem where tradition and technology converge. It offers a replicable model for other endangered craft traditions, combining heritage, education, and innovation in a holistic, adaptable system. The framework also strengthens community resilience and supports cross-sector collaboration, aligning closely with national agendas and global sustainability targets. Moving forward, SCIP holds promise for deeper integration into formal design curricula, public policy, and creative industry development. It invites future researchers, educators, policymakers, and artisans to explore its application, fostering innovation that is culturally rooted, educationally enriching, and economically viable. In essence, the SCIP Framework demonstrates how traditional knowledge, when meaningfully transformed through sustainability-centric practices, can drive future-ready solutions honouring heritage while building pathways for enduring cultural and economic resilience.

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